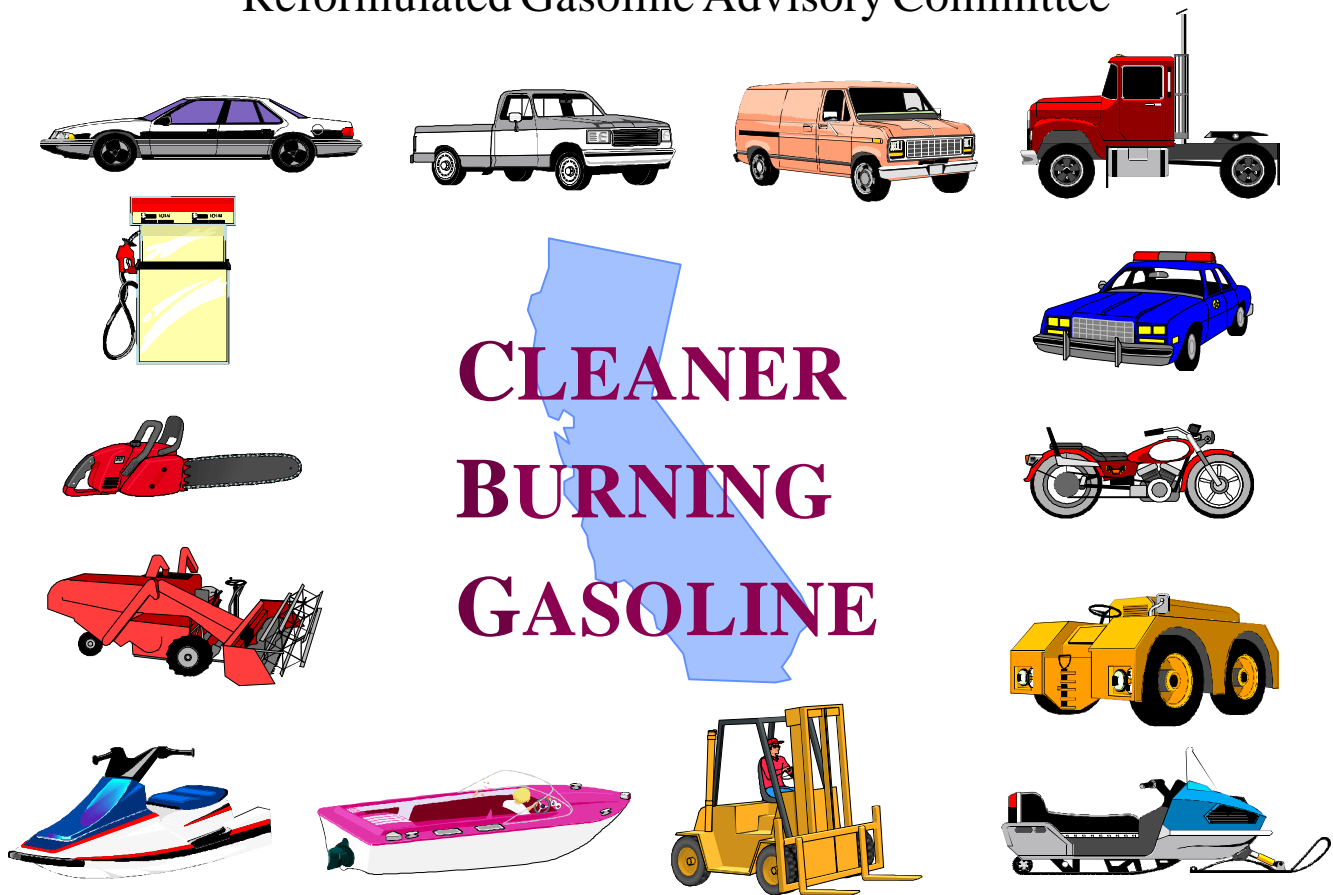


# CaRFG Performance and Compatibility Test Program

## Executive Summary

Report of the Performance Subcommittee of the California  
Reformulated Gasoline Advisory Committee



California Environmental Protection Agency



**Air Resources Board**

*Report of the Performance Subcommittee  
of the California Reformulated Gasoline Advisory Committee*

**Executive Summary**

**California Reformulated Gasoline:  
Performance and Compatibility Test Program**

**California Environmental Protection Agency  
Air Resources Board  
March 1996**

## **Acknowledgments**

This is to acknowledge the many people who contributed to this report.

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## **EXECUTIVE SUMMARY**

### **CALIFORNIA REFORMULATED GASOLINE COMPATIBILITY AND PERFORMANCE TEST PROGRAMS**

#### **A. Introduction**

Motor vehicles and their fuels are major contributors to California's air pollution problems. To address these problems, the Air Resources Board has adopted stringent emission controls on motor vehicles and their fuels. In 1991, the Air Resources Board adopted the California reformulated gasoline (CaRFG) regulations to require cleaner-burning gasoline. The reformulated gasoline program is a critical component of the State Implementation Plan to reduce air pollution and meet the requirements of the 1990 amendments to the federal Clean Air Act.

As one of the largest emission control measures in the last decade in California, cleaner-burning gasoline will immediately reduce air pollution. Smog-forming pollutants will be reduced by 15 percent, the equivalent of removing 3.5 million cars from California roads. Carbon monoxide emissions will be reduced by 11 percent. Emissions of benzene, a toxic air contaminant which causes cancer in humans, will be reduced 50 percent.

#### **B. California Reformulated Gasoline Advisory Committee**

Since 1991, the Air Resources Board has been working closely with industry and other interested parties to implement the regulations. In July 1994, the Air Resources Board formed the California Reformulated Gasoline Advisory Committee to advise it on the implementation of these regulations. To fulfill its obligations, the Advisory Committee formed subcommittees on three topics: performance, transition, and public education. The members of the Advisory Committee and its subcommittees are from the motor vehicle manufacturing and petroleum industries, gasoline distribution and marketing associations, consumer and public interest groups, fleet administrators, and equipment manufacturers (See the Acknowledgement page for a list of the Performance Subcommittee Members.)

#### **C. Compatibility and Performance Test Programs**

Under the guidance of the Performance Subcommittee, extensive testing of CaRFG was conducted in a wide variety of on- and off-road vehicles and equipment.

Beginning in February 1995, the following major test programs were initiated:

- On-Road Vehicle Test Program
- Industry-Sponsored Test Programs
- Off-Road Vehicle and Equipment Test Programs

The report on the *California Reformulated Gasoline Compatibility and Performance Test Programs* contains more detail on these test programs. Part One contains the On-Road Vehicle Test Program, Part Two contains the Industry-Sponsored Test Programs, and Part Three contains the Off-Road Vehicle and Equipment Test Programs.

The goal of these test programs is to determine if there may be performance and compatibility problems with using CaRFG. The Performance Subcommittee provided guidance on designing the test plans and test protocols. Along with the data from the on-road vehicle test program, historical maintenance records and fuel economy records were obtained so that the historical values could be compared with the test results.

**Technical Review Panel:** To ensure that the test program data collected were thoroughly evaluated, the Performance Subcommittee formed a technical review panel. (See the Acknowledgement page for the list of Technical Review Panel Members.) In each case where a fuel system problem occurred, the technical review panel evaluated the fuel system incident to determine if the fuel caused the problem, potentially caused the problem, or did not cause the problem. For the off-road vehicle and equipment test programs, the equipment manufacturers and the Air Resources Board evaluated and determined if the fuel system problem was fuel related.

#### **D. Performance Subcommittee Findings From the Three Test Programs**

##### **1. Findings from the On-Road Vehicle Test Program**

- Results from the performance test program indicate that CaRFG (California Reformulated Gasoline) performed as well as conventional fuel in terms of driveability, starting, idling, acceleration, power, and safety.
- Both the test and control fleets experienced similar fuel system problems on a small percentage (3 percent) of their vehicles. These included problems involving:
  - fuel pumps,
  - carburetors,
  - leakage in fuel hoses and various gaskets (seals), and
  - fuel tanks and tank components.

- Comparison of the overall problem frequency between the test and control fleets indicates that there is no meaningful difference between the frequency of problems in the fleets operated with CaRFG versus the fleets operated with pre-1996 (conventional) gasoline (See Table 1).
- Newer vehicles in the test and control fleets (1991 and newer) did not experience fuel system problems. The problems that occurred were seen in both the test and control fleets in older vehicles (pre-1991), generally with high mileages. The average model year of vehicles experiencing fuel system problems was 1986 and the average odometer reading was 95,000 miles, with a range of 24,000 to 202,000 miles.
- Evaluation of the historical maintenance and repair data shows an increasing rate of failures in fuel system components associated with aging. The overall frequency of problems for both the test and control fleets (3 percent) is well below the expected frequency determined from the baseline historical data of 7,000 vehicles (10 percent) for equivalent time periods. The problems seen in the historical data are the same types as seen in the test and control vehicles.
- Evaluation of on-road fuel economy data indicates that use of CaRFG will reduce the average miles per gallon (fuel economy) by 1 to 3 percent. The 1 percent reduction results from comparing CaRFG to an oxygenated conventional gasoline; since oxygenates are already in widespread use in California, the 1 percent reduction is the expected average fuel economy change when CaRFG is introduced.

## **2. Findings from Industry Sponsored Test Programs**

- The auto industry (GM, Ford) bench tests evaluated the effects of several CaRFG and conventional fuels on unused fuel system elastomers and plastics and on metal wear. The elastomer and plastic property changes and the metal wear rates observed in these studies are not expected to adversely affect fuel system performance in use.
- The Nissan test data indicate no adverse formation of deposits from use of CaRFG.
- The Harley-Davidson test program showed that the use of CaRFG in motorcycles caused no fuel system related problems.
- The Chevron employee fleet study was designed to complement the larger Air Resources Board fleet test program, with more emphasis on older, higher mileage and imported vehicles. Incorporating the Chevron data into the Air

Resources Board test program data does not change the findings described above; however, within the context of the Chevron test program, there were more incidents in the test fleet than the control fleet. The Chevron incident frequency rate is lower than the baseline failure rate that was found from Air Resources Board's review of the historical fleet repair records. The Chevron results are consistent with the results of the other test programs and review of repair records for vehicles operating on CaRFG and conventional gasolines indicates that older, higher mileage vehicles may have a higher risk of fuel system problems.

- The results of the two Texaco limited studies indicate that a switch from high to very low aromatic fuels might accelerate the failure of some fuel system components (e.g. seals and elastomers) in older, high mileage or extreme service vehicles. The Air Resources Board independently evaluated proprietary refinery data and the California gasoline distribution system. This evaluation indicates that even if very low aromatic gasolines are produced, commingling in the distribution system and dilution in the vehicle tank should dampen gasoline property changes so that consumers should not experience property variations nearly as wide as those evaluated in the Texaco programs.
- EMCO Wheaton evaluated its A4000 series of fuel dispensing nozzles. Based on its test results, the EMCO Wheaton staff indicates that CaRFG is acceptable to use with their A4000 fuel dispensing nozzles.
- Dayco Products evaluated gasoline dispensing hoses. They indicated that the results from the immersion tests on their hoses using the winter and summer fuels were satisfactory, and in some cases better than with some conventional gasolines presently in use.
- Holley Performance Products evaluated power valves and elastomer components used in carburetors. Holley Performance Products Company concluded: As a result of contact and operation tests, it has been found that California reformulated gasoline "... has no detrimental effect on Holley fuel handling products."
- United States Department of Energy evaluated the long term effects of cleaner-burning gasoline on five vehicles. They did not report any compatibility problems. They also report a reduction in fuel economy at levels consistent with the fuel economy results from the On-Road test program.

### 3. Results from Off-Road Performance Test Programs

- Review of data from completed off-road test programs shows that the switch to, and the long term use of CaRFG is not expected to adversely affect off-road vehicles and equipment. No problems were experienced due to the use of CaRFG in these engines that could be linked to the fuel.

**Table 1**  
**California Reformulated Gasoline:**  
**On-Road Test Program Data Analysis**

		<b>Test</b>	<b>Control</b>
<b>All Incidents</b>	vehicles	829	637
	incidents	24	20
	percent	<b>2.9%</b>	<b>3.1%</b>
<b>Fuel Pumps</b>	vehicles	829	637
	incidents	12	6
	percent	<b>1.4%</b>	<b>0.9%</b>
<b>Carburetors</b>	vehicles	335	197
	incidents	8	7
	percent	<b>2.4%</b>	<b>3.6%</b>
<b>Hoses</b>	vehicles	829	637
	incidents	3	0
	percent	<b>0.4%</b>	<b>0.0%</b>
<b>Seals</b>	vehicles	829	637
	incidents	0	3
	percent	<b>0.0%</b>	<b>0.5%</b>
<b>Tanks</b>	vehicles	829	637
	incidents	0	4
	percent	<b>0.0%</b>	<b>0.6%</b>
<b>“Other”</b>	vehicles	829	637
	incidents	1	0
	percent	<b>0.1%</b>	<b>0.0%</b>

Source: Air Resources Board. December 1, 1995. *Air Resources Board Oracle Database Systems: Reformulated Gasoline Project*. Sacramento, California.

## **E. Description of On-Road Vehicle Test Program**

The On-Road Test Program began in February 1995 and ended in August 1995. The On-Road Test Program consisted of 1,466 on-road vehicles. The vehicles were drawn from the following eight fleets:

- Bank of America
- California Department of Transportation
- City of Sacramento, Police Department
- County of Sacramento
- California State University, Fresno
- General Telephone & Electronics
- Pacific Bell, Northern California
- Pacific Bell, Southern California

The eight fleets included passenger cars, and light-, medium-, and heavy-duty trucks, including a variety of makes and models. The vehicles had seen different types of service and included a wide range of model years, from 1964 to 1995, with odometer readings as high as 230,000 miles. The average model year and mileage of test vehicles were 1988 and 60,000 miles, respectively. These compare closely with the on-road light-duty vehicles that are used in California today; the average model year for these vehicles is 1988 and the average mileage is 84,000.

By testing a large number of vehicle types under real world conditions, the effects of CaRFG on vehicle performance and engine and fuel system components were investigated. The fuel system components included fuel pumps, fuel hoses, fuel injectors, carburetors, and seals. During the test program, the vehicles were inspected every other month, and the data collected included vehicle descriptions, fuel use, and performance observations.

The eight fleets included a test group of 829 vehicles, which were driven over 5,000,000 miles on CaRFG test fuel and a control group of 637 vehicles which were fueled with commercially available conventional gasoline. Table 2 contains the test fuel specifications. The Performance Subcommittee agreed that this fuel should resemble the gasoline that will typically be available to consumers on June 1, 1996 when the standards go into effect at the retail markets. The test fuel met the CaRFG specifications in Table 2 within the reproducibility of the test methods. The test fuel also met Reid vapor pressure requirements for the winter and summer seasons.

**Table 2**  
**California Reformulated Gasoline: Test Fuel Specifications**

	Winter	Summer
RVP, psi	11 to 12	6.5 to 6.9
Aromatic content, vol.%	18 to 20	18 to 20
Olefin content, vol.%	3.0 to 5.0	3.0 to 5.0
Sulfur content, ppmw	15 to 25	15 to 25
Benzene content, vol.%	0.5 to 1.0	0.5 to 1.0
Oxygen content*, wt.%	~2	~2
T50, °F	190 to 210	190 to 210
T90, °F	280 to 300	280 to 300

\* Methyl-tertiary-butyl-ether at 10.8 to 11.2 volume percent.

## **2. Baseline Data**

Supplemental, historical data were obtained from the same organizations that operated the On-Road test fleets. These data are significant because they were used to establish normalized rates of incidents for the test and control fleets. The normalized rates are the basis for comparing the test and control fleets. The baseline data included maintenance and repair records for the calendar years 1993 and 1994 on over 7,000 vehicles.

## **3. Fuel Economy**

The various studies conducted by government and industry were reviewed and analyzed for the effects of gasoline properties on fuel economy. The fueling records from the On-Road test fleet, along with the historical records for 1994, were compared with records from the control group. In addition, laboratory dynamometer testing on selected vehicles was also performed by the Air Resources Board to evaluate fuel economy.

## **F. Description of Industry-Sponsored Test Programs**

To augment the On-Road test data, several companies from the Performance Subcommittee conducted tests.

### **1. Chevron U.S.A. Products Company Test Program**

The Chevron U.S.A. Products Company conducted a test program over 4.5 months. The objective of the program was to test a blend of CaRFG using an employee fleet with vehicles that were slightly older and included more imported vehicles than the On-Road test

fleets. The Chevron program fleet included 118 test vehicles and 117 control vehicles. The Chevron test fuel met the CaRFG regulations, but did not have all the same fuel properties as the On-Road test fuel in Table 2.

## **2. Dayco Products and EMCO Wheaton Test Program**

The Dayco Product Incorporated and EMCO Wheaton, Incorporated tested CaRFG on dispensing equipment. The Dayco Products tested three hoses to determine if cleaner-burning gasoline changed the characteristics of the hoses. The hoses were tested for hardness, elongation, elasticity, strength, durometer changes, and swelling changes. The EMCO Wheaton evaluated the effects of CaRFG on four nozzles. These nozzles were tested for mechanical wear and deterioration.

## **3. Ford Motor Company Test Program**

The Ford Motor Company assessed the lubricity characteristics of the following four fuels:

- On-Road test fuel
- On-Road test fuel, blended with ethanol
- On-Road test fuel, with low aromatic content
- industry average gasoline

The results were compared with the characteristics of 15 other fuels that had been tested previously.

## **4. General Motors Company Test Program**

The General Motors Company conducted a series of bench tests on various unused elastomers and plastics that are used in vehicle fuel systems. The following fuels were tested:

- On-Road test fuel
- On-Road test fuel, blended with ethanol
- On-Road test fuel, with low aromatic content
- industry average gasoline
- American Society for Testing and Materials reference fuel C

The elastomers and plastics were examined for changes in swell, elongation, hardness, strength, volume, and density.

## **5. Harley-Davidson Company Test Program**

The Harley-Davidson Company conducted a comprehensive test program including bench and in-use testing. The On-Road test fuel was compared to gasolines in the Wisconsin and Alabama markets. Eleven motorcycle engines, representing a cross-section of engine families, models, and mileage, were evaluated for performance, durability, emissions, and fuel economy.

## **6. Holley Performance Products Test Program**

Holley Performance Products Incorporated tested materials used in their products using the On-Road test fuel. Thirty power valves were tested over 500,000 cycles, which represents over 5 million miles traveled. Once completed, the power valves were checked for leaks, durability, and functionality at the manufacturing facility. Nine different components were also tested for degradation, functionality, swelling, flexibility, and compressibility. Holley Performance Products also analyzed the failed parts from the On-Road Vehicle Test Program for the cause of their failure.

## **7. Nissan Motor Company Test Program**

The Nissan Motor Company tested the effects of a reformulated gasoline and conventional gasoline on engine deposit formation. Two vehicles were subjected to over 30,000 miles of driving, and the intake and exhaust valves and pistons were then evaluated for deposits.

## **8. Texaco Refining and Marketing Incorporated**

Texaco Refining and Marketing Incorporated conducted two separate test programs to evaluate the effects of changing from relatively high aromatic content fuels, about 40 percent, to very low aromatic content fuels, five, six, and ten percent aromatic content. (The cap limit in the CaRFG regulations is 30 percent maximum.)

The Bakersfield, California fleet consisted of 27 refinery vehicles, which were subject to extreme service conditions. Prior to the test program, all 27 vehicles were operated on gasoline with a 40 percent aromatic hydrocarbon content. For the first two weeks of the test program, 13 vehicles remained on the 40 percent aromatic content gasoline and were changed to five percent low aromatic content CaRFG for the final two weeks. The remaining 14 vehicles were operated on ten percent aromatic content CaRFG for the first two weeks and were changed to five percent aromatic content CaRFG for the final two weeks.

In Beacon, New York, the fleet consisted of 41 vehicles which were operated by their owners, Texaco employees. The model years of the vehicles ranged from 1965 to 1992 and included passenger cars and light- and medium-duty trucks. For this test program, all of the

vehicles were operated on conventional gasoline with 35 percent aromatic content for three weeks. During the next three weeks of the test program, half of the vehicles were changed to six percent aromatic content CaRFG, and the other half were switched to 49 percent aromatic content gasoline. For the final three weeks, the vehicles using six percent aromatic content CaRFG were switched to 49 percent aromatic content gasoline, and the vehicles operating on 49 percent aromatic content gasoline were switched to six percent aromatic content CaRFG.

## **9. United States Department of Energy**

The objective of the Department of Energy (DOE) sponsored test program is to evaluate the long term effects of CaRFG used in five vehicles. The vehicles tested were in-use 1994 model year California vehicles that had initial odometer readings of about 20,000 miles. The program studied the effects of switching fuels in vehicles from conventional gasoline to CaRFG. The vehicles were operated for 30,000 miles on the road using CaRFG. The performance as well as fuel economy of these vehicles were monitored.

### **G. Off-Road Vehicles and Equipment Test Programs**

The off-road test programs included an Air Resources Board sponsored test program and manufacturer-sponsored test programs. Two and four cycle engines were included in the programs. The following major categories of off-road vehicles and equipment were covered:

- Utility, Lawn, and Garden Equipment
- Pleasure Craft and Small Marine Engines
- Agricultural/Industrial/Construction Equipment
- Personal Watercraft
- Snowmobiles

#### **1. Utility, Lawn, and Garden Equipment**

The utility, lawn, and garden equipment form the largest category of off-road equipment in California. Four separate test programs were conducted on a total of 82 engines, with 52 two-stroke engines and 30 four-stroke engines.

The Air Resources Board program tested 49 utility, lawn, and garden engines in-use at the California State University Fresno Grounds Division. The Portable Power Equipment Manufacturers Association also provided new equipment for testing at Fresno. The fleet accumulated approximately 3,000 hours of operation over ten weeks.

The Tecumseh Products Company tested 21 small utility, lawn, and garden engines on CaRFG; the lawn mowers were operated for 150 hours, garden tractors for 350 hours, and tillers for 75 hours. The Briggs and Stratton Corporation tested several four-stroke engines on CaRFG and federal reformulated gasoline.

Several equipment manufacturers with the Portable Power Equipment Manufacturers Association tested CaRFG on hand-held equipment. The equipment was tested from three to 150 hours. The following members of Portable Power Equipment Manufacturers Association have completed testing: Echo-Kioritz and Andreas Stihl. As of the preparation of this report, several additional off-road equipment test programs are continuing. They include Dolmar Makita, Homelite, and Poulan/Weed Eater.

## **2. Pleasure Craft and Small Marine Engines**

Two test programs were conducted on pleasure craft and small marine engines. In cooperation with Mercury Marine, a test program was conducted over ten weeks on 95 boats using CaRFG test fuel at Lake Cachuma Boat Rentals. This fleet is primarily used in a recreational setting. The boats were equipped with two-stroke engines with less than 25 horsepower.

In a second test program with Mercury Marine, the Paradise Watercraft Boat Rentals and South Shore Parasailing tested a total of thirteen boats, eight using CaRFG test fuel and five using conventional gasoline. The boats are used for recreational purposes, with a mixture of cruising and water skiing. Over a ten week period, the test fleet accumulated a total of 858 hours and used 4,363 gallons of fuel.

## **3. Industrial, Construction, and Agricultural Equipment**

Over a ten week period, California State University Fresno operated a total of eighteen vehicles and equipment engines on CaRFG. The equipment included utility carts, forklifts, tractors, riding mowers, and assorted construction equipment.

The California Department of Transportation tested five vehicles and equipment over a five month period. The fleet consisted of forklifts and miscellaneous construction equipment.

## **4. Personal Watercraft**

In cooperation with Arctco Incorporated, the Paradise Watercraft Boat Rentals and South Shore Parasailing tested eleven Tigershark personal watercraft for ten weeks using the CaRFG test fuel. The personal watercraft were equipped with two-cycle engines.

## **5. Snowmobiles**

In cooperation with Arctco Incorporated, the Lake Tahoe Winter Sports Center evaluated the CaRFG test fuel in ten snowmobiles for six weeks in Hope Valley, California. The snowmobiles accumulated over 25,000 miles.